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VOLUME 81 PAPER No. 853

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

DECEMBER, 1955

KELLY AIR FORCE BASE MAINTENANCE HANGAR: ENGINEERING DESIGN FEATURES

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STRUCTURAL DIVISION

{Discussion open until April 1, 1956}

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

FOREWORD

In the past decade, remarkable progress has been made in the construction of large span, single story structures. The engineer of today, equipped with the facility of modern techniques is faced with a variety of important and decisive factors in the selection of method of design, construction and the application of structural material. To evaluate a building project, one must have intimate knowledge of the natures of the problems involved and the scope of the work within the established limitations of the functional requirements. It is intended, in this three-paper symposium, to bring out the interesting features and kindred interrelationships in planning, design and construction of the large span, single story hangar structure with all the supporting utilities.

The three papers comprising the symposium on the "Kelly Air Force Base Maintenance Hangar" are sub-titled "Planning" by Louis A. Nees, A.M. ASCE, Proceedings Paper 852; "Engineering Design Features" by N. H. Aslanian, A.M. ASCE, Proceedings Paper 853; and "Construction Features" by W. H. Fasshauer, A.M. ASCE, and C. W. Edwards, Proceedings Paper 854.

The first paper of the group describes the basic studies of the Air Force operational and functional requirements. The major feature of interest is in its provision to enable maintenance on a simultaneous "production line" and "stall" basis for all types of aircraft, including the largest bombers (B-36, B-52, and B-47) in operation today. The planning established a facility consisting of a hangar 2,000 ft. long, 300 ft. wide area flanked by a shop structure 250 ft. wide, plus a maintenance type apron of 300,000 square yards. As a result, aircraft can be handled on a production line basis and "staged" in or out of the line depending on the scope of work involved while at the same time the facility supports "stall" type overhauls on the apron.

The second paper of the group covers mostly design, fabrication and method of erection of the principal hangar structure, and also general features of interest, including foundations, apron slabs and all the supporting facilities.

The last paper of the symposium discusses in detail all the construction activities and the execution of the project up to completion. This maintenance hangar facility totalling a record-breaking hangar and shop roof area of 23.4 acres and measuring slightly less than a mile in perimeter will be completely ready for occupancy by mid-February 1956, and will be the world's largest and most modern hangar structure.

The first two papers of the Symposium on "Planning" and "Engineering Design Features", by Messrs. L. A. Nees and N.H. Aslanian, respectively, have been programmed to be presented at the American Society of Civil Engineers' meeting in Dallas, Texas, in February 1956.

This paper was published at 2500 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N.Y.

KELLY AIR FORCE BASE MAINTENANCE HANGAR: ENGINEERING DESIGN FEATURES

N. H. Aslanian,* A.M. ASCE

SYNOPSIS

This paper is presented with the express purpose of providing the essential engineering design features of a large-span single story hangar facility and its supporting utilities that are now under construction for the United States Air Force. Two other papers, describing in detail the over-all planning and the construction features of this project, have been presented by L. A. Nees,[1] A.M. ASCE, and Messrs. W. H. Fasshauer,[2] A.M. ASCE, and C. W. Edwards,[2] respectively.

INTRODUCTION

A recent accomplishment in the field of airport facility design, which may be of general interest to the profession, is a structural steel hangar with an adjoining maintenance shop structure, totaling a record-breaking ground floor area of over 1,000,000 sq. ft., or an equivalent roof area in excess of 23. acres. An additional 62,500 sq. ft. of floor area on the second floor provided administrative offices and facilities for personnel, including a cafeteria and other features of safety and comfort. Included in the project, is a new apron slab covering an area of 300,000 sq. yds., a boiler house, 83 ft. x 55 ft. in area, a pump house, 46 ft. x 46 ft. in area and an elevated water storage tank with a capacity of 550,000 gal. The hangar and shop areas are provided with deluge sprinkler system, overhead cranes and all the necessary utilities such as power, heat, water, compressed air and sewerage.

This new $12,687,000 maintenance facility, measuring 2,000 ft. in length, and slightly less than a mile in perimeter, is now under construction for the United States Air Force at Kelly Air Force Base, in San Antonio, Texas. When completed at about the end of this year, 1955, it will be the world's largest and most modern hangar structure. By comparison, the facility will be 2.4 times larger in area than the present record-breaking maintenance hangar constructed in 1953 for the Eastern Air Lines at the Miami International Airport.

The prime feature of interest is not only the record-breaking size of the structure, but also that it holds a new concept of integrated maintenance facility design, which is most significant in its functional characteristics.

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This military installation will be the first of its kind that will enable maintenance on a simultaneous "production line" and "stall" basis for all types of aircraft, including the world's largest bombers in operation today.

The preliminary studies of all Air Force operational and functional requirements were made by the Air Materiel Command, Wright-Patterson Air Force Base, Ohio. The size, the type and the space assignment patterns of this structure are based on these initial studies.[1]

Preliminary Studies

The problem imposed on the Architect-Engineer in designing the principal hangar structure was to employ a method of design and construction and choose a material that would provide maximum over-all economy within the established limitations of functional requirements. The basic requirement of the 2,000-ft. long and 300-ft. wide hangar structure was to provide a minimum clear height of 60 ft. over the entire floor area and to allow four (4) 250-ft. wide door openings, one at each end and two (2) on the side, and also to make provision for three (3) additional side entrances for the future.

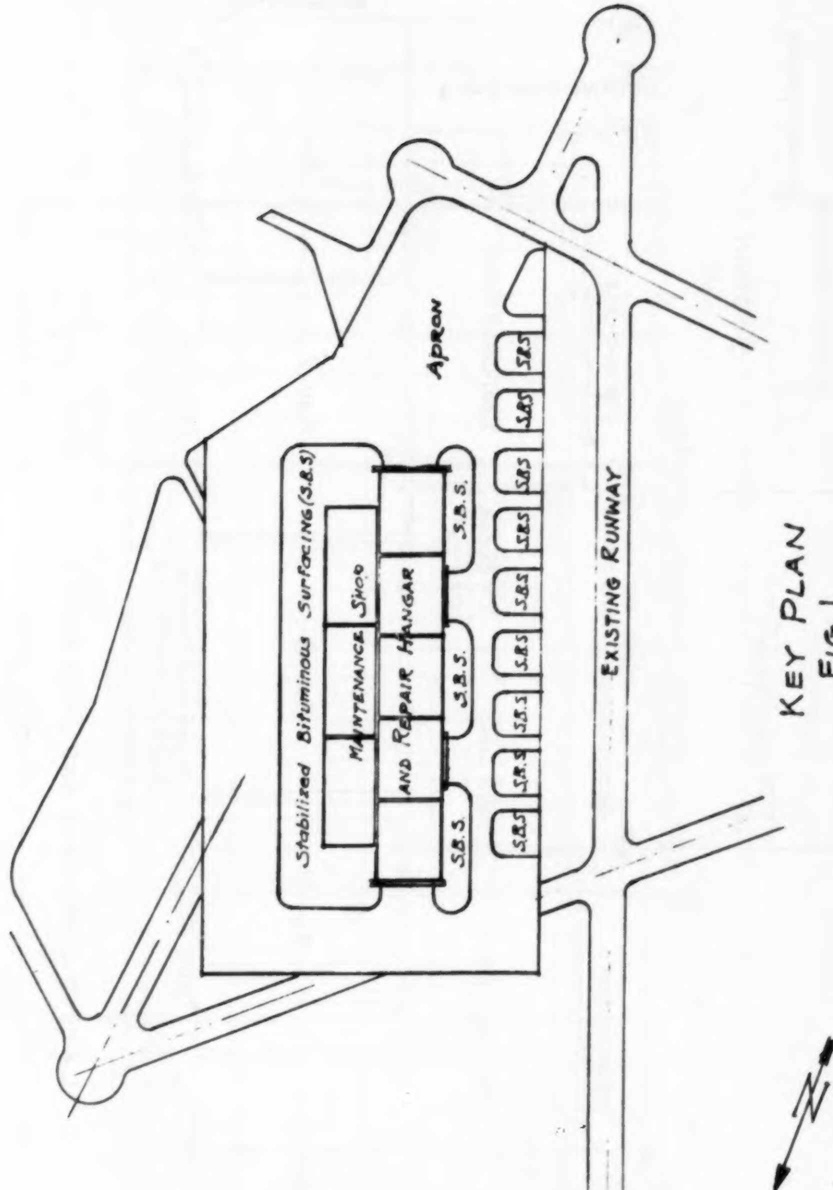
To meet the above requirements, it was necessary to develop a system of framing that would provide five (5) 250-ft. wide and 60-ft. clear high sidedoor openings, spaced 150 ft. apart along the 2,000 ft. stretch, and two (2) similar end door openings.

Considerable thought was given to various methods of design and construction and to the choice and application of structural materials. Many useful possibilities were abandoned owing to a number of decisive factors such as immoderately large spans required in both directions, established minimum clear height, maximum over-all building height, concentrated moving crane loads, and preferable flat roof with no exposed sky hooks or suspender frames.

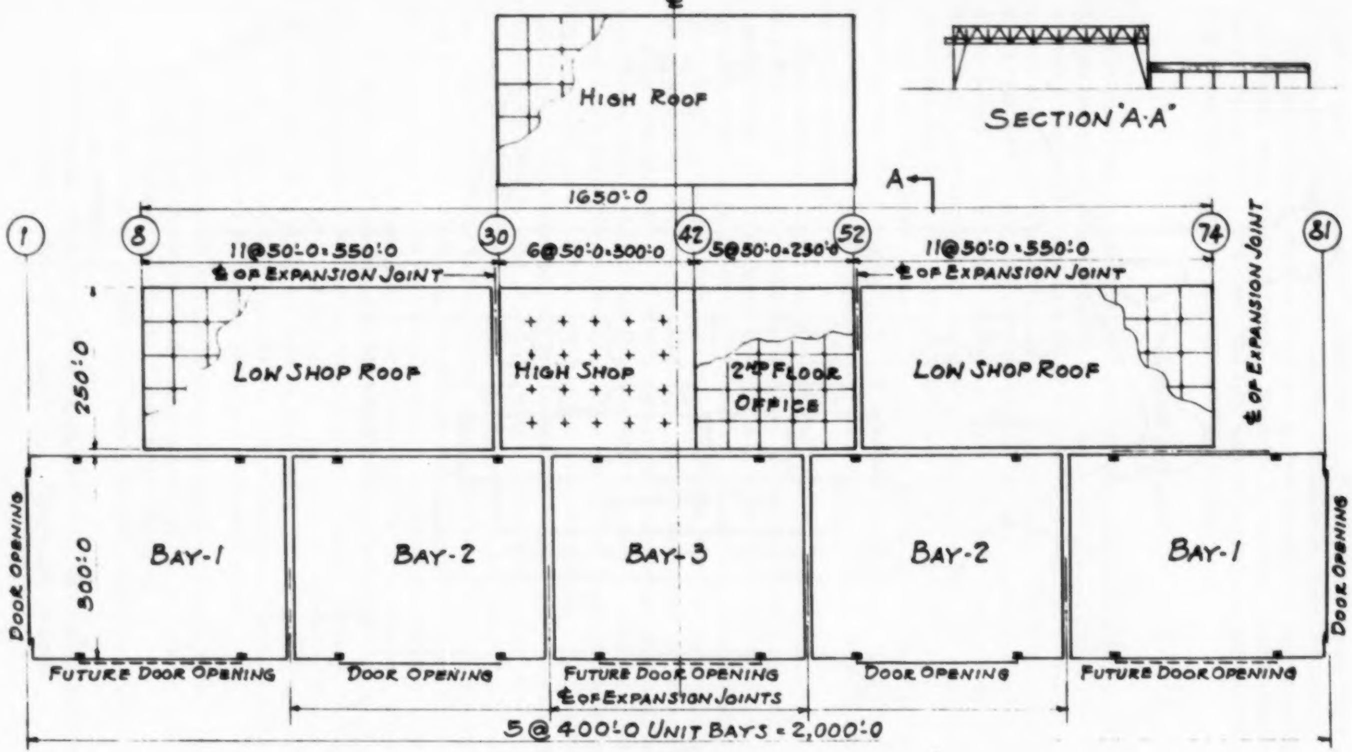
Arch type structure, either in reinforced concrete or steel, did not merit recommendation since it required excessive rise and could not meet the functional requirements economically. The qualitative comparisons revealed obvious advantages in favor of rectangular rigid-frame-type building for best meeting the conditions established by the functional requirements. The material chosen for this type of framing was a conventional structural carbon steel, because it afforded speed of fabrication, erection and greater ultimate load-carrying capacity due to its ductile structural characteristic. Consideration was given also to structural low alloy steel (silican and nickel steel) for the large span trusses and frames. However, pertinent studies and inquiries to major steel mills indicated no particular advantage in over-all economy.

On the basis of rectangular rigid-frame-type building, comparative studies were made of five different combinations of framings to adopt the most efficient and economical framing system. Parallel top and bottom chord trusses were maintained in all these studies to provide desirable flat roof and to eliminate truss-work and bracings for the crane runways. The five comparative preliminary studies of hangar structure were as follows:

a) Five independent unit bay structures 400 ft. x 300 ft. each. The longitudinal double cantilever trusses spaced 36 ft. on centers resting on a pair of rigid truss frames 250 ft. apart (Figs. 2, 3).
b) Same as Item (a) except longitudinal double cantilever trusses spaced 25 ft. on centers.
c) Continuous longitudinal trusses spaced 36 ft. on centers supported on rigid truss frames 250 ft. and 150 ft. alternately spaced.

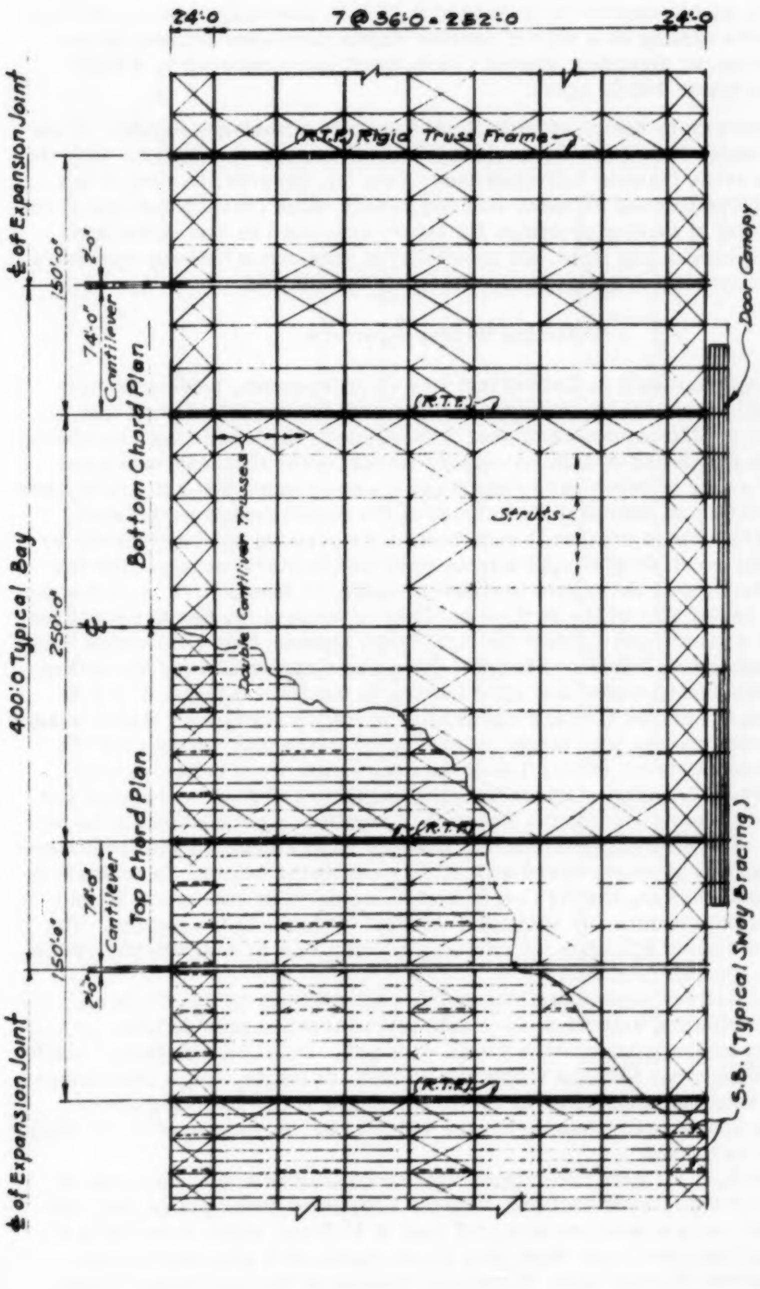


KEY PLAN
FIG. I



LAYOUT OF HANGAR AND SHOP AREAS

FIG. 2



TYPICAL TOP AND BOTTOM CHORD FRAMING OF HANGAR BAY

FIG. 3

d) Same as Item (c) except continuous longitudinal trusses spaced 25 ft. on centers.
e) Five independent unit bay structures 400 ft. x 300 ft. each. The transverse double cantilever trusses with 62.5 ft. overhangs spaced 25 ft. on centers resting on a pair of carrier double cantilever trusses on the longitudinal direction, spaced 175 ft. apart and supported by a rigid truss frame 250 ft. apart.

The preliminary design studies showed definite advantages in favor of the structure under Item (a). The economy in steel tonnage ran parallel with the continuous truss framing indicated under Item (c), however, in view of the thermal and settlement stresses induced in continuous framing and also from the standpoint of making provision for future expansion in convenient and economical hangar bay units, the possibility of continuous framing was ruled out and the structural system under Item (a) was adopted.

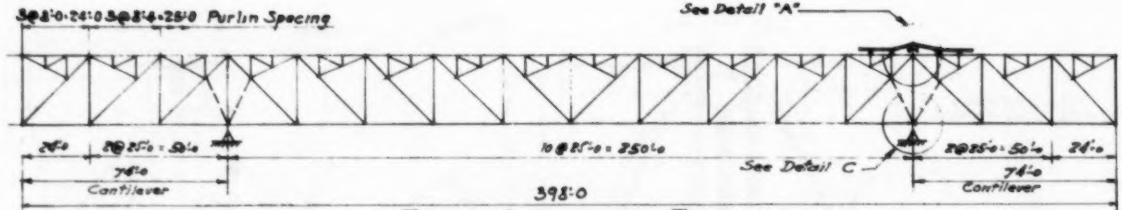
Principal Hangar Structure

The hangar building is divided into five (5) independent, self-supporting and basically identical bay structures. The roof framework of each unit bay consists of ten (10) double cantilever trusses along the longitudinal direction, 398.0 ft. in length and 36.0 ft. on centers (except outer trusses), which are framed to a pair of two-hinged rigid truss frames spaced 250.0 ft. apart, thus allowing 74.0 ft. of overhang at each end of the double cantilever trusses (Figs. 3, 11). These cantilever ends reduce the positive bending moment by 36%, thereby permitting an appreciable reduction in steel tonnage. The top chord center line of the double cantilever trusses is kept 1 ft.-3 in. below the top chord center line of the 24 ft.-9 in. deep rigid truss frames to permit the cantilever ends to pass through the rigid truss frames, thus eliminating undesirable connections subject to fatigue. A common center line for the bottom chord members of trusses and rigid frames is maintained (Figs. 4, 5 & 6).

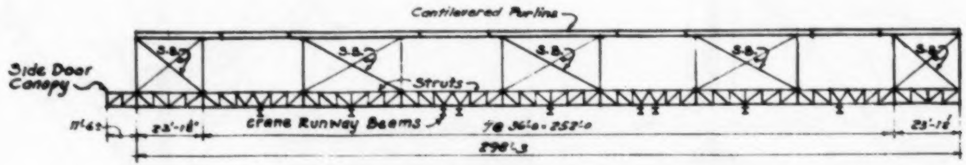
The hangar roof purlins are designed of so-called continuous hinged beams (cantilevered beams), with hinges introduced at every other panel near the points of contraflexure (within 1/6 of the span length from either support). This system of framing provides balanced negative and positive bending moments, and is more economical than that of continuous beams since it takes advantage of 33% reduction in section modulus when compared with continuous beams, and 50% when compared with simply supported beams. In contrast to the continuous beams, the yielding of elastic supports of continuous hinged beams will not produce any additional flexural stresses in the purlins. The purlins are spaced 8 ft.-4 in. on centers and span 36.0 ft. between the double cantilever trusses (Fig. 3).

This method of framing exhibits an inherent economy in materials and costs. The abutting ends of double cantilevered trusses provide ideal location for expansion joints at each 400 ft. of length. Possible differential settlements of hangar bay footings within the 2,000 ft. of length, would develop appreciable settlement stresses in the main framing if the structure were continuous for its entire length, but the 400 ft. x 300 ft. independent unit bays alleviate this hazard.

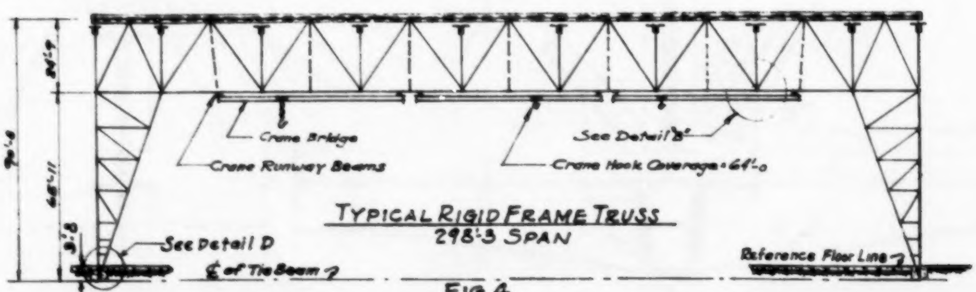
The 298 ft.-3 in. span two-hinged rigid truss frames are constructed of 14 in. rolled wide flange sections, with the necessary cover plates, and are designed to carry a dead and live roof load of 51.5 psf, which amounts to a load of 10.3 kips per linear foot, plus three cranes with maximum lifting capacity of five (5) tons each. Horizontal thrusts of the rigid truss frames



TYPICAL CANTILEVERED TRUSS

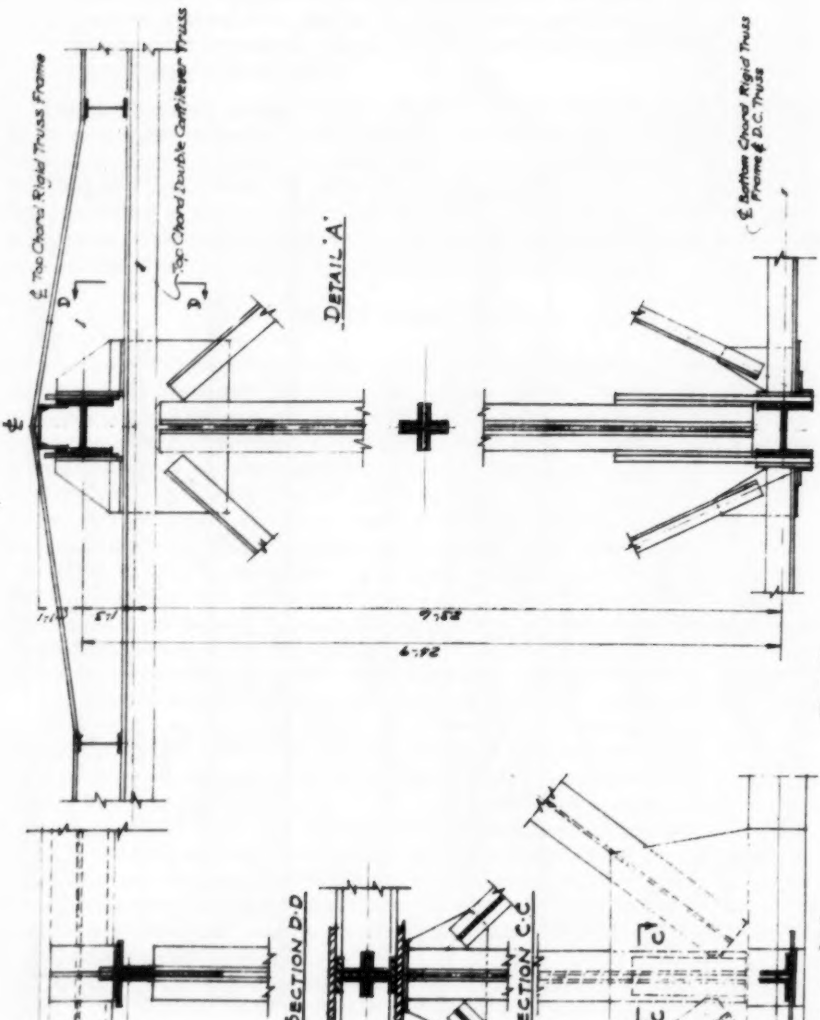


TYPICAL TRANSVERSE CROSS SECTION OF HANGAR BAY FRAMEWORK



TYPICAL RIGID FRAME TRUSS
298'-3 SPAN

FIG. 4



℄ Top Chord Rigid Truss Frame
Top Chord Double Cantilever Truss
DETAIL 'A'
℄ Bottom Chord Rigid Truss Frame & D.C. Truss
DETAIL 'C'
SECTION D-D
SECTION C-C
DETAIL 'B'

FIG. 5

ISOMETRIC VIEW AT THE POINT OF INTERSECTION OF DOUBLE CANTILEVER TRUSS TO THE RIGID TRUSS FRAME.

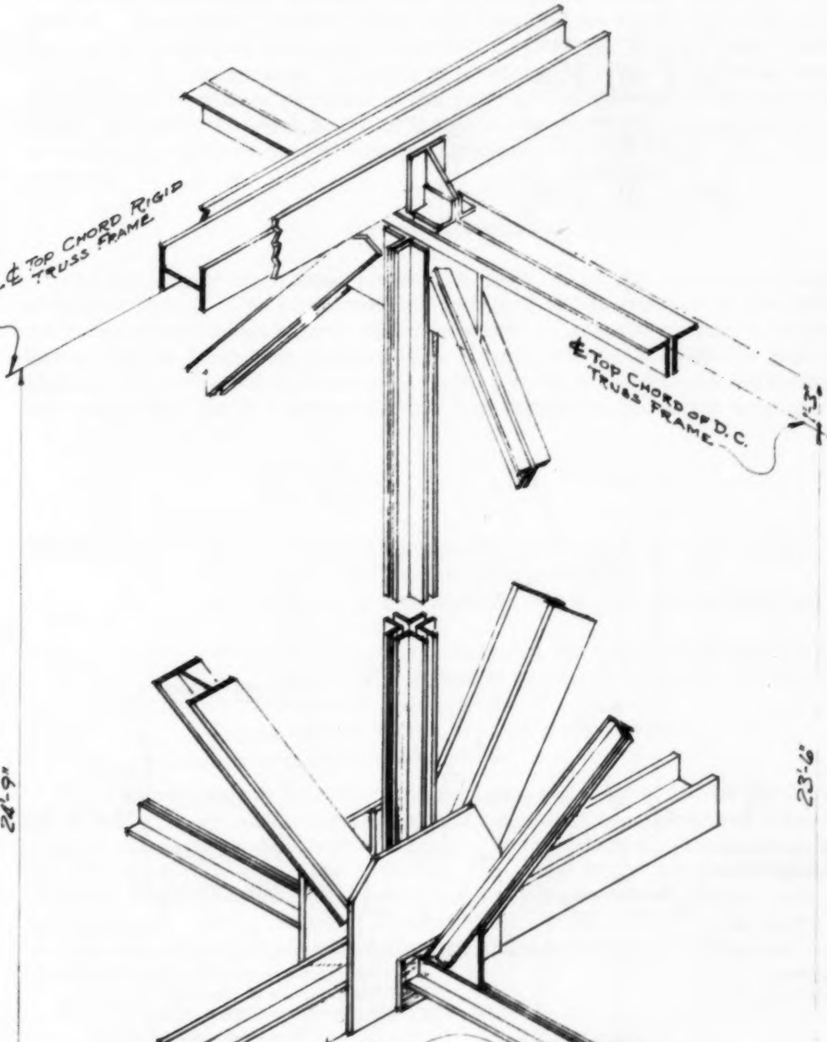


FIG. 6

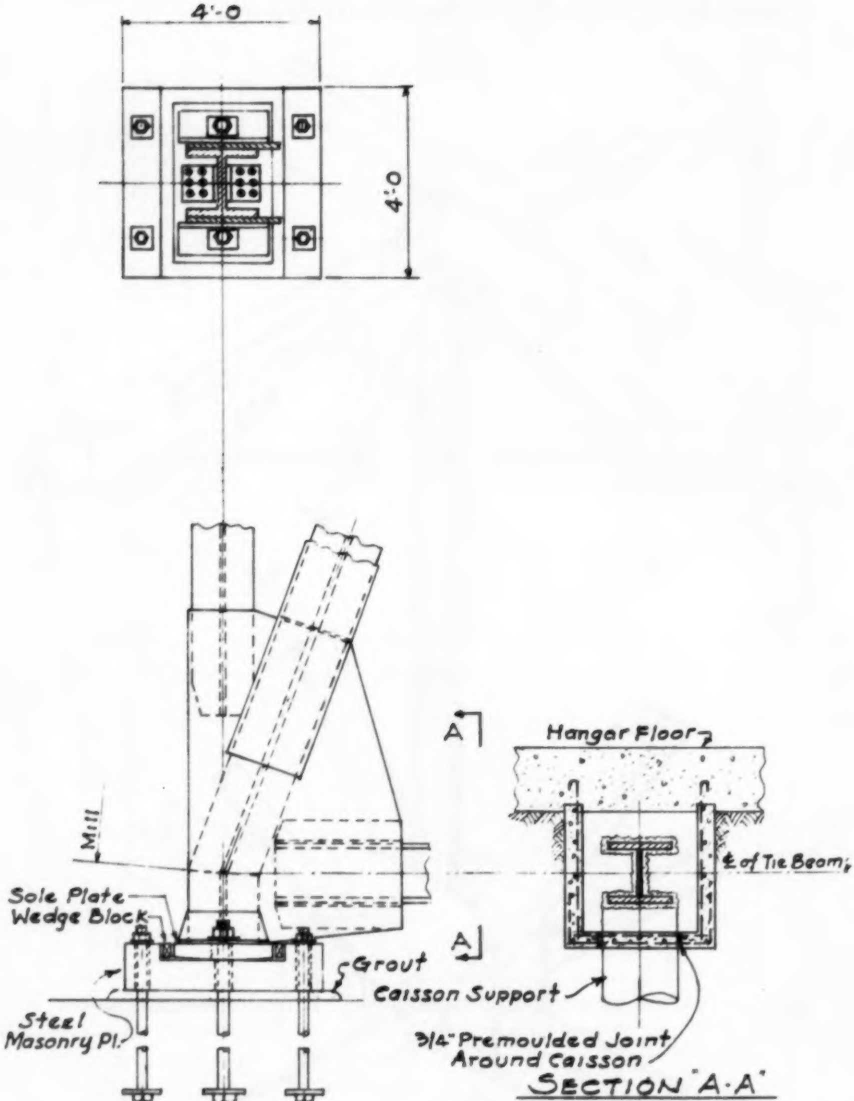

4'-0
4'-0
Mill
Sole Plate
Wedge Block
Grout
Steel
Masonry Pl.
A
A
Hangar Floor
℄ of Tie Beam
Caisson Support
3/4" Premoulded Joint
Around Caisson
SECTION "A-A"
DETAIL "D"

FIG. 7

are resisted by a wide flange tie member connected to the hinged column base by common flange gusset plates (Fig. 7). The rigid truss frame also will resist a horizontal wind force of 32 psf (pressure and suction combined) which produces a total horizontal force of 358.0 kips on any one frame.

The flat roof area is covered with 20-gage metal decking and 4-ply built-up roofing. Glass-fiber insulation has been provided for the entire roof area. The metal decking is adequately welded to the roof purlins to furnish lateral resistance for the purlins. In order to eliminate warping of the metal decking, side trusses have been provided at the exteriors to maintain uniform deflections. To facilitate truss action of the side trusses, slotted connections are provided at the top of the intermediate columns at every panel point, 25 ft. on centers.

Method of Design

The two-hinged rigid truss frame was designed by the conventional method of elastic theory. The horizontal component of either reaction as the only statically indeterminate force was determined by general method of assuming one of the two-hinged supports to be on rollers, and by equating the expression for its horizontal displacement under a given load, with the deflection of the same point due to a horizontal unit load applied at the roller support.

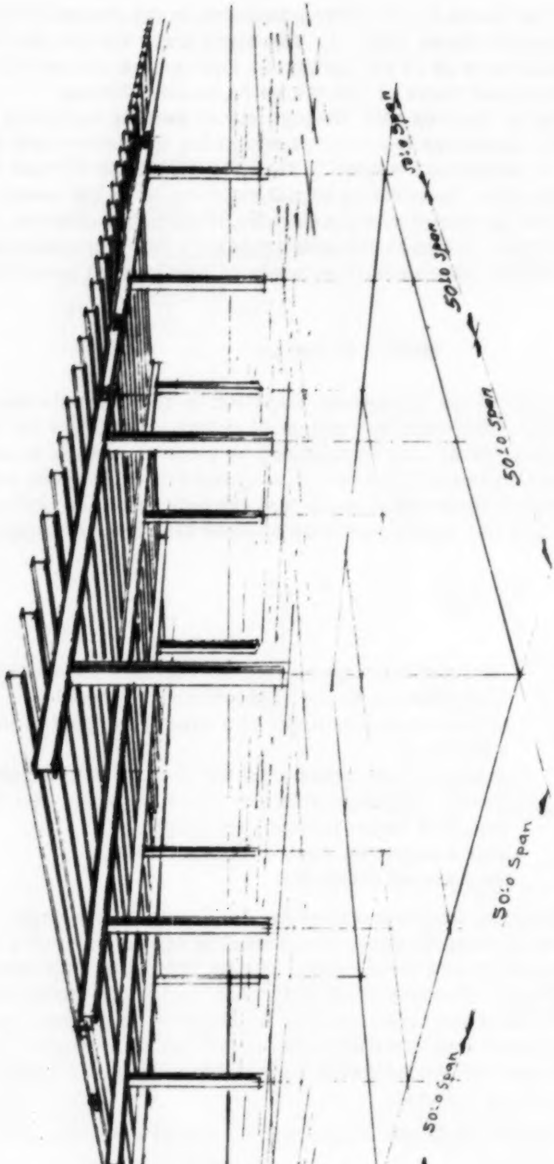
$$\sum \frac{S_1 uL}{AE} + H \sum \frac{u^2 L}{AE} = 0$$

where,

- H = horizontal component of the reaction under a given load (The statically indeterminate force)
- S_1 = stress in any member of a simply supported truss with $H = 0$
- u = stress in any member of the truss due to a unit horizontal load applied at the roller support. $H = 1.0$
- L = length of truss member (in inches).
- A = cross sectional area of truss member.
- E = modulus of elasticity.

The factors influencing this expression are many. In a two-hinged rigid truss frame, a member cannot change its geometric length nor can a base support rotate or be displaced horizontally without setting up stresses throughout the entire structure. The redundant horizontal force and the internal stresses are a function of the cross section make-up of the various parts of the structure. The calculated internal stress equilibrium would be upset in various degrees because of the following items which affect the sensitiveness of two-hinged rigid truss frames:

a) Horizontal translation of the base supports due to elongation of the tie member.
b) Rise and fall of temperature under various climatic conditions and also temperature variations between the time of fabrication and erection.
c) Inaccuracies in the fabricated lengths of the truss members.
d) Inaccuracies in field measurements and in locating of the anchor bolts and base plates.
e) Slippage in connection joints.
f) The condition of end supports. The restraint provided by the foundations, the floor slabs, etc.



TYPICAL SHOP FRAMING SYSTEM
50'-0 x 50'-0 MODULAR
FIG. 8

In determining the redundant horizontal reaction, the expression given above was modified to include rise and fall of temperature (rise 30° F., fall 50° F.), elongation of tie member and an arbitrary restraint provided by the foundation supports after completion of erection.

Shop Framing

The maintenance shop structure, 1,650-ft. long and 250-ft. wide, adjoining the hangar, is divided into three (3) equal and independent parts, each 550-ft. long, thus providing expansion joints at third points and also along the side adjacent to the hangar. The clear height of the two end divisions is 20 ft. and the high bay at the central division is 37 ft. high.

The framing design of the shop structure may be described as a series of 50 ft. by 50 ft. modular type of design, each composed of four (4) columns supporting two girders with cantilevered ends. These girders, in turn, support a series of purlins also with cantilevered overhangs at each end. The cantilevered girders and beams overhang only about 1/6 of the span from each end, at minimum zones of stress, the remaining 2/3 of the span consists of a suspended member simply connected between the cantilevered ends (Figs. 2, 8).

This method framing offered economy in material and cost.

Expansion and Flexibility

The need for future expansion was considered during the preliminary stages of planning. The location of this facility on the site allows space for future expansion in multiples of 400-ft. unit bays at both ends of the hangar structure. The shop structure is designed for future expansion in multiples of 50-ft. bays in all three directions. Two 250-ft. side doors are provided in the 2,000-ft. length of the hangar (one in each of the two of the five 400-ft. bays). Additional 250-ft. side door openings can be provided in any of the other three (3) bays by tearing out the siding and placing the necessary rails, door guide boxed channels and doors.

Windowless Corrugated Walls

The outside walls of the hangar and the shop area consist of a 5-ft. high masonry unit wall from floor to top of cement sill. From this sill to the roof, the wall is of corrugated asbestos siding with glass-fiber insulation. The glass-fiber heat insulation used on the walls, the hangar door and the roof areas, also features a sound absorbing quality that will reduce the noise level within the building. In general, no windows have been provided for the walls (Fig. 12). Windows are installed only where daylight is desirable, such as office areas and cafeteria. The girt framing consists of 9-in. channels, spaced 5 ft.-6 in. on centers and supported at 25-ft. intermediate columns. Sag rods are used to suspend the girts at the third points. The employment of corrugated cement asbestos was found not only to be low in cost, but also to provide a frangible low-resistant skin that will "blow-off" readily when subjected to air-blast pressures from nuclear weapons. The skin increases the chance that the structural frame will survive such an attack with minor damage. The use of windowless walls not only reduced the cost but also resulted in a structure that is considerably safer and easier to protect against the large scale radio-active fall out effects associated with thermonuclear weapons.

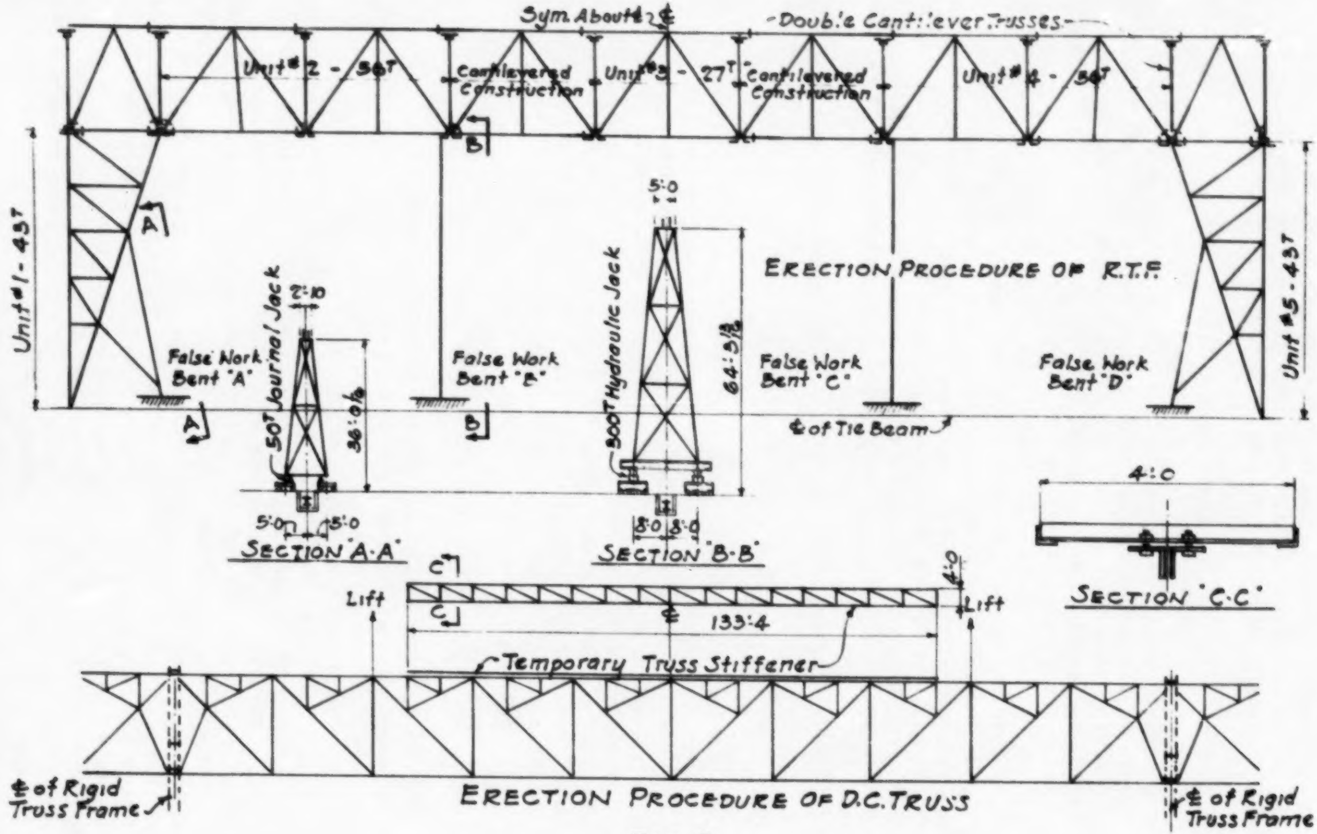

Sym. About ℄
-Double Cantilever Trusses-
Unit# 2 - 36T
Cantilevered Construction
Unit# 3 - 27T
Cantilevered Construction
Unit# 4 - 36T
Unit# 1 - 43T
Unit# 5 - 43T
ERECTION PROCEDURE OF R.T.F.
False Work Bent "A"
False Work Bent "B"
False Work Bent "C"
False Work Bent "D"
℄ of Tie Beam
50T Journal Jack
2:10
36:0½
5:0
5:0
SECTION "A-A"
300T Hydraulic Jack
5:0
64:3½
8:0
8:0
SECTION "B-B"
4:0
SECTION "C-C"
Lift
Lift
4:0
133:4
Temporary Truss Stiffener
℄ of Rigid Truss Frame
℄ of Rigid Truss Frame
ERECTION PROCEDURE OF D.C. TRUSS

FIG. 9

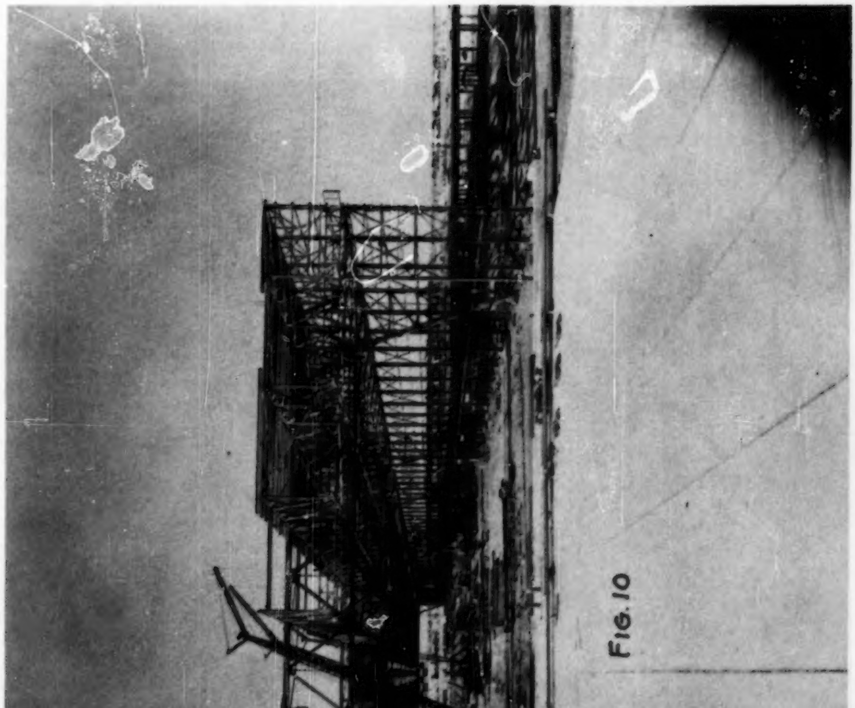


FIG. 10

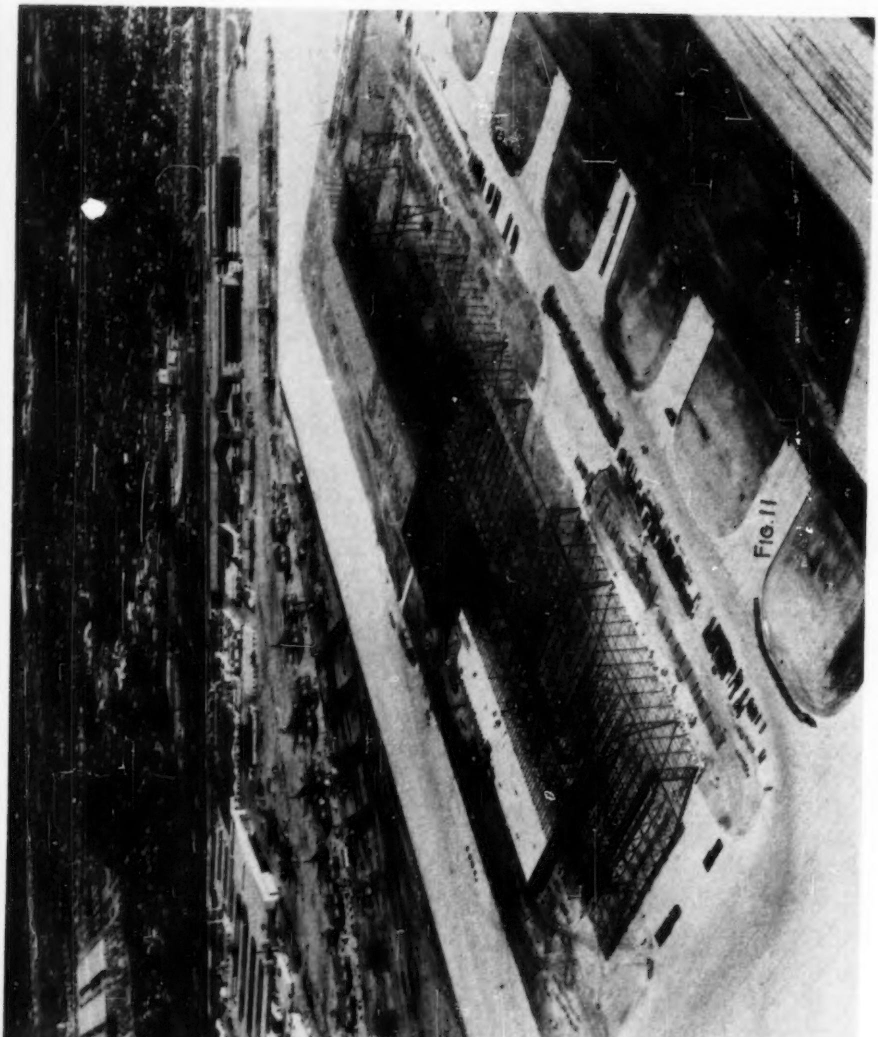


FIG.11

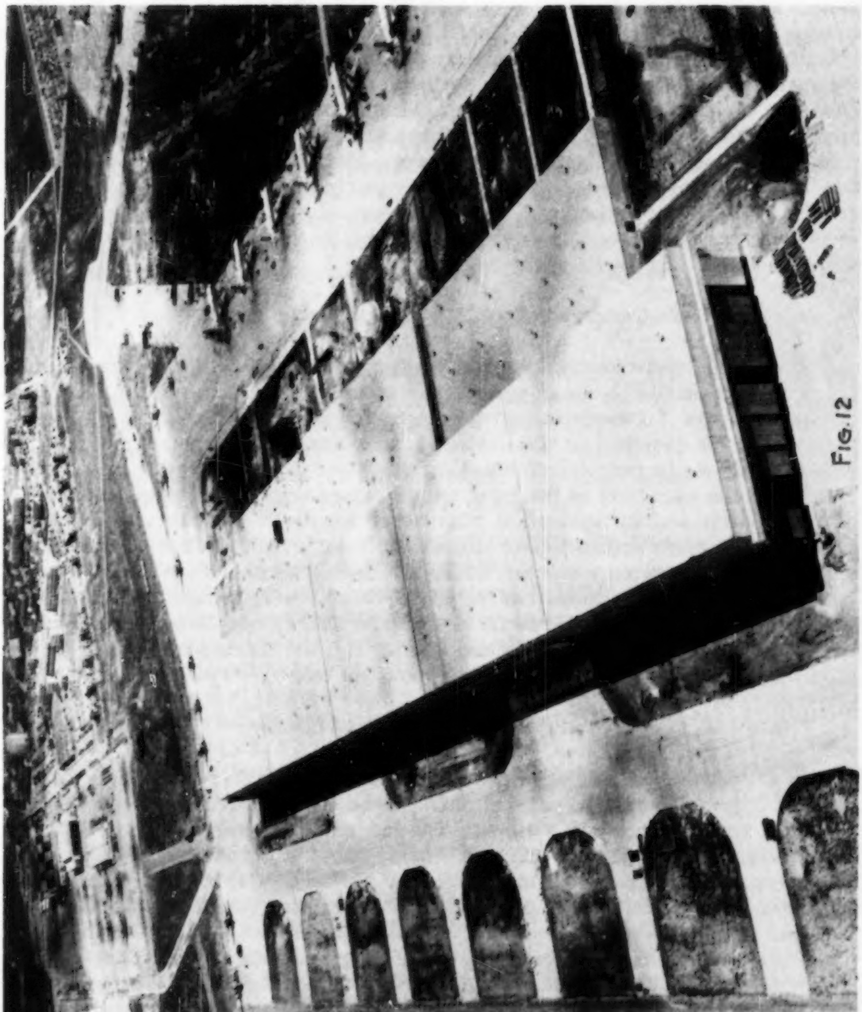


FIG. 12

Crane Loads and Runways

Three cranes with maximum capacity of 5 tons and crane hook coverage of 64 ft. each, are provided side by side at the bottom chord elevation of the hangar roof structure. Maximum crane reaction of 20 kips was assumed for design. Only one crane bridge will be used on each runway. Crane runway beams are suspended by steel cables (at 25-ft. on centers) to permit the continuous rails, running the full 2,000 ft. length of the hangar, to expand and contract freely at both ends, independently of the roof trusses. The high bays of the maintenance shop assigned for engine repair, are provided with 5-ton capacity monorails running both ways. Maximum monorail crane reaction is approximately 14 kips. The shop low bays are designed for 2-ton capacity cranes with monorails extending both ways. Maximum monorail crane reaction is about 6 kips. Shop roof girders are designed for one monorail crane reaction in center of all spans. Shop foor purlins are designed for one-half monorail crane reaction in center of all spans, so that a pair of roof purlins will support one monorail crane reaction.

Fabrication and Camber of Rigid Truss Frames

As a special workmanship requirement, the fabrication of rigid truss frames was specified to be in accordance with the "Specification for Steel Railway Bridges," American Railway Engineering Association. All rivet holes were sub-punched or sub-drilled 1/4 in. small and were reamed to size with all members assembled. To reduce secondary stresses, the fabrication and the assembly of the rigid truss frames was specified to be based on "Geometric angles" instead of "Cambered Angles." The fabricator was required to submit computations of the shop lengths, and Williot Diagrams showing that the frame members under full dead load plus an average crane load stresses, would assume essentially their geometric length, and members would become straight and free from secondary stresses. A permanent camber of 3 in. was provided at the center of rigid truss frames in addition to the slightly over 4 in. of flexible camber, taken out mostly by the dead load.

Structural Joints and Connections

In the preliminary stages of design, comparative studies were made of welded, bolted and riveted connections. These studies revealed basic disadvantages against the use of welding. The large span truss frames, with heavy wide flange sections (14 WF 320) and cover plates in excess of 2.5 in. in thickness, were not considered suitable for welding. The rigid truss frames requiring forcible initial bending of the members for reducing secondary flexural stresses would have presented many difficulties in field welding. The structural steel had to conform to the requirements of Federal Specification (QQ-S-741, Type II) which limits the carbon and the manganese content in steel to provide better weldability. All in all, inadequate shop facilities, inferior field conditions, and costly inspection ruled out welding possibilities of principal connections.

At the time of these studies, in the Fall of 1952, the major steel fabricators in the country were asking permission to substitute high-tensile bolts for rivets, primarily because riveting crews were difficult to obtain, and also because bolting offered speed in erection of steel. The qualitative studies at that time revealed no particular structural advantage in favor of bolted

connections. On the contrary, inadquate experimental data, uncertain functional behavior of bulky splice connections (with the length of bolt grip in excess of 7 inches), unsatisfactory control of the required tension in the bolts by torque wrenches, special requirement to avoid shop painting of faying surfaces, and, also, constant and costly field inspection did not favor recommendation of bolted joints.(3) As a result, conventional riveted joints were specified for all principal connections.

It is interesting to note that since that time, the high-tensile bolts have started gaining popularity through the strength of favorable experimental research data, improved torque wrenches, modified specifications and added experience.(4,5)

In general, 7/8-in. diameter rivets are used throughout the structures, except that 1-in. diameter rivets are used for rigid truss frame connections. Unfinished bolts 3/4-in. diameter are used for purlins (4-in. flanges) and girts. Some welding was allowed for column base plates, connection angles and secondary members. A continuous weld was required for the boxed door-guide channels to reduce condensation inside the boxed sections.

Erection Procedure

To assure safe and speedy erection of the long span rigid truss frames and double cantilever trusses, conferences were held with the fabricator's representatives and the erection procedure was established to provide simplicity, safety and economy.

The sequence of erection for any one of the principal hangar bay structures (300 ft. x 400 ft.) was specified to be as follows:

1) Install the sub-base steel masonry plates with the necessary grouting, and anchor bolt in their indicated position.
2) Thoroughly lubricate the contact surfaces between masonry plates and the sole plates. The specified No. 22-gage stainless steel sheets applied on the contact surfaces shall be uniformly brush-coated with a special lubricant immediately before these surfaces are brought in contact.
3) Assemble and rivet tie beams on the ground. Wrap tie beams with a protective covering and place in trench (Fig. 7).
4) Erect stiff leg unit #1 (43 tons) and falsework bent "A" (equipped with a pair of 50-ton journal jacks) on the shop side. Lock the sole plate at the heel of the stiff leg in centered position. Connect the tie beam to the heel connection plates (Fig. 9).
5) Erect falsework bent "B" (equipped with a pair of 300-ton hydraulic jacks) and guy in position.
6) Assemble and rivet rigid truss frame unit #2 on the ground. Erect the assembled unit #2 and support the free end on the falsework bent "B" (Fig. 9).
7) Repeat the above procedure for the second rigid truss frame, 250 ft. away.
8) Assemble and rivet on the ground longitudinal trusses 250 ft. long and 24 ft. - 9 in. deep immediately over the stiff legs. Place temporary truss stiffeners on the top chord to secure lateral stability and to overcome horizontal buckling during erection (Fig. 9).
9) Erect the longitudinal trusses over the stiff legs. Fill in the bottom and the top laterals and sway bracings.
10) Erect intermediate columns and wall framing on the shop side.

11) Assemble and rivet two cantilever ends on the ground. Erect and fill in top and bottom laterals and sway bracings between the two.
12) Repeat steps 4 to 7 at the opposite end (unit #5 same as unit #1) except the sole plates, which are to be placed unlocked in a calculated "geometric" distance of approximately 1-3/8-in. (determined from Williot diagram) toward center of hangar to provide connection of unrestrained tie member. This dimension is based on normal fabricating shop temperature of 68° F. and shall be left free to self-adjust for any temperature variations in the field.
13) Erect interior portions of both rigid truss frames and allow to cantilever beyond the falsework bent "B" and "C."
14) Assemble and rivet on ground unit #3 for both rigid truss frames.
15) Erect unit #3 (27 tons); jack up falsework bents to the amount necessary to make connection.
16) Assemble and erect the longitudinal trusses (double cantilever) in the same sequence and continuity as step 8, filling in between trusses with the struts and sway bracings (Fig. 10).
17) Erect outside columns and wall framing.
18) Remove falsework bents and allow the sole plate to slide and approach the established column grid line. In the event the sole plate is restrained by friction, apply hydraulic jacks to accomplish this operation. The sole plate at this stage shall be level with the steel masonry plate to maintain uniform bearing.
19) Lock the sole plates in position permanently with wedge blocks and fill the slotted holes with lead.

To obtain the proper camber, all cantilever ends of double cantilever trusses were erected with necessary shims, 1/2-in. in thickness at the bottom chord connections, to the rigid truss frames.

Hangar Doors

The hangar area is provided with four (4) 250-ft. wide and 60-ft. clear high door openings. Each door is constructed of eight (8) metal leaves and is equipped with bearing-type double-flange bottom wheels rolling horizontally on ride rails cast in the door track footing. Top rollers are guided within a pair of boxed channel sections welded toe to toe. These so-called telescoping doors are operated by a built-in electric motor controlled by constant-pressure type push-buttons, and are stacked in pockets at each end when in the open position. No windows are provided for the 250-ft. wide doors, since they will remain open most of the time (Fig. 12).

To facilitate ease of transportation, the 31-ft. wide door units were subdivided into three smaller and separate panels, each slightly more than 10 ft. wide. The panels were shipped separately, then bolted together at the site.

The design criteria and functional requirements of these doors are essentially the same as established in the standard double cantilever hangars designed for the Corps of Engineers, U. S. Army[6] except that the doors of the Kelly Hangar do not require enclosure insert panels, since the entire plane is brought inside the hangar.

Soil Conditions - Foundation Design

Sub-surface exploration data, boring logs and laboratory soil tests and investigations for the hangar and the apron areas were supplied by the Air

Materiel Command. Because of the unusual characteristics reported on the above data, typical undisturbed samples taken from borings were sent to the Soils Testing Laboratory of Columbia University and were examined in significant detail as to their essential characteristics.

The general soil conditions at the site consist of an average 3 ft. of black clay, stiff to hard in condition. Below this, and extending to a depth of 13 to 14 ft., is a limy clay, light gray in color, and hard to stiff in condition. The free lime (caliche) content of this clay decreases with depth. From this point to about 19 ft. in depth, is a hard, crumbly, very silty clay, very dense and relatively incompressible. Beginning at about 19 ft. depth and extending to about 34 ft. is a gravelly stratum of hard clay. From this point, and extending to a depth of about 66 ft. is a stratum of hard, tough, yellow and tan clay. This material contains fine sand lenses at some parts, and below 60 ft. it contains occasional layers of tough dark gray clay. This stratum was found to be very strong, and of low compressibility. From 66 ft. to the maximum explored depth of 90 ft. there is a hard, tough, dense clay, dark gray to black in color. This material known as "Taylor Clay" or "blue shale" by local engineers does not break up on drying and is very strong and of very low compressibility.

Settlement analysis for the footings of rigid truss frames, at higher elevations, showed the footings would have to be quite large in order to keep settlements within non-objectionable values of less than 1 in.

As a result of the objectionable shrinkage or detrimental bearing of the expansive soils due to capillary saturation under seasonal soil moisture fluctuations, the hangar footings and all other footings subjected to heavy loadings are founded on caissons which are locally known as "under-reamed piling." The bottoms of the caisson piles are founded on the very hard Taylor Clay or shale formation, at a depth of 60 to 65 ft. below grade, and are required to be under-reamed and belled out to provide sufficient bearing area to carry the design loading at a bearing value of 20,000 lbs. per sq. ft. The bearing value is based on very conservative assumptions; the real factor of safety is actually higher than 4. Because of these highly preconsolidated clays with low compressibility, settlement of the caissons under maximum loading will be very small. The shafts of the caisson piles are adequately reinforced to resist uplift resulting from the expanding soils. Also, the caisson piles supporting the hangar rigid truss frames are adequately reinforced to take bending caused by the lateral forces resulting from wind loads on the hangar structure.

Provision is made to keep wall cracking to an absolute minimum by supporting the grade beams on caissons. A minimum clearance of 4 in. at the underside of grade beams is furnished to prevent contact with the swelling clays. The tops of concrete slabs, and also apron slabs, are placed 3 in. below the tops of grade beams due to the expected uplift caused by the swelling clays. Differences between the grade beams and the floor at the door openings are taken up by means of temporary bitumastic ramps as required.

The horizontal tie beams of the rigid truss frames also are supported on caissons with sufficient underside clearance to prevent contact with expansive soil.

Concrete Apron and Floors

The 300,000 sq. yds. of the apron slab, and, also, the hangar floor are designed to support heavy aircraft loads of 400,000 lbs. with twin tandem wheels, and 190,000 lbs. with twin wheels. The design of concrete pavements was

based on Westergaard's Emperical Method, as adopted by the Corps of Engineers.(8) A slab thickness of 16 in. was required with temperature reinforcing, consisting of No. 6 welded wire mesh 6 in. x 6 in. spacing; based on a subgrade with a K value of 150 psi per in. and concrete with flexural strength of 700 psi at 28 days. Hangar floors are reduced in thickness of 12 in. for a 50-ft. strip around the sides that will not be subjected to heavy loadings.

Provisions have been made in the apron and the hangar slabs for dowel bars, temperature reinforcing, sealing of joints, and those joints adjacent to existing pavements.(8)

The shop floors are made of 6-in. thick reinforced concrete with a compressive concrete strength of 3,000 psi at 28 days. The reinforcing steel consists of No. 6 welded wire mesh with 6 in. x 6 in. spacing.

Bituminous stabilized surfaces for protection against infiltration of rain water or against excessive evaporation of soil moisture during the dry seasons, are provided in areas between the apron and the hangar and wherever the loading is light (Figs. 1, 12).

Perforated drain pipes placed under the gravel-filled drainage ditches are provided on three sides of the apron below the outside edges to intercept any seepage of rain water through open cracks on the uphill sides and to prevent it from running under the paved areas. An entirely separate storm water drainage system is provided along the North-West corner to carry off storm water directly into the nearby creek.

General Utilities

All corrugated sidings and the metal roof are insulated with Fiberglas giving an equivalent heat transmission "U" value of 0.34.

The heating system is designed to provide an indoor temperature of 50° F. for the hangar and 70° F. for the shop, with the outside temperature of plus 20° F. and a wind velocity of 15 mph. The Boiler House consists of two (2) 50,000#/hr. boiler fired by natural gas. Steam is generated and supplied to the hangar at a pressure of 125 PSIG for heating and process.

The fire protection system consists of a "deluge" system in the hangar area with draft curtains under the roof to control the number of heads that come into play. The shop area is protected with conventional "wet" head system within fire-wall enclosed areas. A 550,000-gal. elevated outdoor steel storage tank furnishes the water to six (6) centrifugal motordriven fire pumps of 2,500 gpm each. These, in turn, pump the water through a piping loop supplying all sprinklers and hydrants. Adequate drainage is provided for the hangar floor areas by 18-in. floor drains, sized to carry off quickly the discharge of the deluge sprinkler systems to the storm sewer. The spacing was designed to confine spilled and burning gasoline in as small an area as practicable. Slip joints are furnished at the floor slabs to provide freedom of movement for the pipes due to swelling clays.

A combination of mercury and incandescent lamps is furnished for the hangar area with an illumination intensity of 30 ft.-candles. "Slimline" fluorescent lamps were considered more desirable than incandescent lamps for the shop and office areas, because they are more economical to operate and furnish more evenly distributed light. Intensity of illumination at work bench or desk level is 50 ft.-candles.

Supplementary Assignment - Field Supervision

Upon completion of a design project, nothing could be more gratifying to the design engineer than a reassignment engaging his services for the supervision and inspection of construction. An adequate and skillful design confined within the limitations of conventional theories is only effective if the end product is properly fabricated and constructed with modern procedures and carefully prepared specifications.

Realizing the importance of adequate field supervision, the Air Force awarded the contract for supervision of the construction to the designers of this facility in order to obtain the maximum benefits from their intimate knowledge of the work involved. Occasional conferences were held with the steel fabricators' representatives in order to properly establish convenient and suitable methods of fulfilling design and erection requirements. In contrast to the erection procedures developed for the Standard Double Cantilever Maintenance Hangars designed for the Corps of Engineers,[7] the principal hangar structure of the Kelly project did not warrant rigorous control of erection stresses during construction. In the course of the construction period detailed progress reports were sent from the field to the home office engineers for study and evaluation of the construction methods.

The structural steel for the entire project, totaling slightly over 11,800 tons, was fabricated and it has been completely erected by the American Bridge Division, U. S. Steel Corporation, at a cost of $3,676,600.00.

CONCLUDING REMARKS

Realization of the new maintenance hangar at the Kelly Air Force Base, portrays a new concept of integrated maintenance facility and it signifies an up-to-date thinking in military air base installation design. The foregoing presents features of general interest and kindred inter-relationships embodied in design and erection procedures of the Kelly Air Force Base Maintenance Hangar. Sufficient emphasis has been placed on design fabrication and erection of the principal hangar structure. A feature of ranking importance was the exacting care with which the preliminary comparative studies were conducted in design and selection of structural materials within the established limitations of the functional requirements. The modular system of framing adopted for the principal hangar structure, and also for the shop structure, offered economy, alleviated thermal and settlement stresses and provided future expansion in convenient and identical unit bays already designed and detailed.

As a concluding note of interest, the Air Force exercises complete supervision of the over-all project, including operations involving the initial preliminary studies of functional requirements, planning, design, and construction. Periodic conferences were held by the Air Installations Division, Air Materiel Command, Wright-Patterson Air Force Base, Ohio, covering in detail, the entire design and construction aspects of this work.

ACKNOWLEDGMENT

The building was designed by the Kuljian Corporation, Architects & Engineers, Philadelphia, Pa., under the supervision of James L. Cherry, Executive Vice President, M. ASCE, AIA, with W. H. Fasshauer, A.M. ASCE as Project Engineer and S. C. Jemian, M. ASCE, as Chief Engineer. The author was in

direct charge of the structural design. Professor D. M. Burmister, A.M. ASCE, of Columbia University was retained as consultant in soil analysis, foundation studies and subgrade preparation for apron and hangar slabs. The supervision of construction is handled from the Field Office of the Kuljian Corporation at Kelly Air Force Base, Texas, under the direction of C. W. Edwards.

Much credit is given to Ringold Olivier, M. ASCE, Plant Engineer, Alan A. Porter, Engineering Manager, and G. W. Faulkner, Erection Engineer, of the American Bridge Company, for their very able and competent supervision during the fabrication and erection of the structural steel.

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PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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c. Discussion of several papers, grouped by Divisions.